Evaluation Of New Repair Methods For Seal Surface Defects On Reusable Solid Rocket Motor (RSRM) Hardware

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The focus of the evaluation was to develop a back-up method to cell plating for the improvement or repair of seal surface defects within D6-AC steel and 7075-T73 aluminum used in the RSRM program. Several techniques were investigated including thermal and non-thermal based techniques. Ideally the repair would maintain the inherent properties of the substrate without losing integrity at the repair site. The repaired sites were tested for adhesion, corrosion, hardness, microhardness, surface toughness, thermal stability, ability to withstand bending of the repair site, and the ability to endure a high-pressure water blast without compromising the repaired site. The repaired material could not change the inherent properties of the substrate throughout each of the test in order to remain a possible technique to repair the RSRM substrate materials. One repair method, Electro-Spark Alloying, passed all the testing and is considered a candidate for further evaluation.

I. INTRODUCTION

The purpose of the testing was to test several possible methods for improving/repairing seal surface defects within D6-AC steel and 7075-T73 aluminum. The techniques tested were WIRE ARC Spraying, High Velocity Oxygen Fuel (HVOF) Thermal Spraying, Microplasma Transfer Arc (MPTA), Laser Induced Surface Improvement (LISI), Electro-Spark Alloying (ESA), and the application of an Epoxy-Metal Composite (DEVCON). These techniques were analyzed to be possible backups for cell plating being worked on in Utah. The problem with cell plating for the D6-AC is the issue of hydrogen embrittlement. This issue could cause problems in qualifying the cell plating method for RSRM flight requirements due to delayed failure caused by hydrogen embrittlement of the repaired area. The aluminum parts have successfully been repaired by cell plating therefore, this paper has only partial data on aluminum since a backup method was no longer needed.

The design criteria for the repair of RSRM hardware requires that all defects found in the defined seal zone be repaired by blending during the refurbishment cycle prior to flight. Blending creates a smooth transition between the bottom of the defect and the substrate. Damage of sealing surfaces is caused mainly by corrosion, along with assembly and disassembly handling. Damage or defects to the sealing surfaces can compromise the defined seal zone.

The coupons repaired by the various methods were tested by a series of pre-qualification tests including adhesion, surface roughness, thermal cycling, corrosion, and hardness.

II. SUMMARY

There were six different techniques tested during this plan to repair seal surface defects in materials used for RSRM hardware. All methods were tested on D6-AC steel whereas, only three of the methods were used on aluminum due to the success of cell plating on aluminum. The testing done with D6-AC steel will be discussed in the most detail since it is the substrate that a repair method is currently required. Five of the six methods failed at least one of the tests for the repaired coupon. The test all five failed was hardness. The repair methods made the repaired areas different from the substrate material mainly by having a heat-affected area. The only repair method to pass all tests subjected to the repaired material was ESA. ESA appears to be the most promising repair method to do possible further evaluation.

III. REPAIR METHODS

A. WIRE ARC Spraying

In the Arc Spray Process a pair of electrically conductive wires is melted by means of an electric arc. The molten material is atomized by compressed air and propelled towards the substrate surface. The impacting molten particles on the substrate rapidly solidify to form a coating. This process carried out correctly is called a "cold process" (relative to the substrate material being coated), as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material. Arc spray coatings are normally denser and stronger than their equivalent combustion spray coatings. Low running costs, high spray rates and efficiency make it a good tool for spraying large areas and high production rates. Disadvantages of the process are that only electrically conductive wires can be sprayed and if substrate preheating is required, a separate heating source is needed.

B. High Velocity Oxygen Fuel (HVOF) Thermal Spray Process

The HVOF (High Velocity Oxygen Fuel) Thermal Spray Process is basically the same as the combustion powder spray process (LVOF) except that this process has been developed to produce extremely high spray velocity. There are a number of HVOF guns, which use different methods to achieve high velocity spraying. One method is basically a high-pressure water-cooled combustion chamber and long nozzle. Fuel (kerosene, acetylene, propylene and hydrogen) and oxygen are fed into the chamber; combustion produces a hot high-pressure flame, which is forced down a nozzle increasing its velocity. Powder may be fed axially into the combustion chamber under high pressure or fed through the side of a laval type nozzle where the pressure is lower. Another method uses a simpler system of a high-pressure combustion nozzle and air cap. Fuel gas (propane, propylene or hydrogen) and oxygen are supplied at high pressure, combustion occurs outside the nozzle but within an air cap supplied with compressed air. The compressed air pinches and accelerates the flame and acts as a coolant for the gun. Powder is fed at high pressure axially from the center of the nozzle. The coatings produced by HVOF are similar to those produced by the detonation process. Coatings are very dense, strong and show low residual tensile stress or in some cases compressive stress, which enable thicker coatings to be applied than previously possible with the other processes. The very high kinetic energy of particles striking the substrate surface does not require the particles to be fully molten to form high quality coatings. This is certainly an advantage for the carbide cermet type coatings and is where this process really excels.

C. Microplasma Transfer Arc (MPTA)

The process of MPTA is implemented by the use of plasma, a gas that is heated to an extremely high temperature and ionized so that it becomes electrically conductive. Similar to GTAW (TIG), the plasma arc welding process uses this plasma to transfer an electric arc to a work piece. The metal to be welded is melted by the intense heat of the arc and fuses together. In the plasma welding torch a tungsten electrode is located within a copper nozzle having a small opening at the tip. A pilot arc is initiated between the torch electrode and nozzle tip. This arc is then transferred to the metal to be welded. By forcing the plasma gas and arc through a constricted orifice, the torch delivers a high concentration of heat to a small area. With high performance welding equipment, the plasma process produces exceptionally high quality welds.

D. Laser Induced Surface Improvement (LISI)

The LISI process uses high-powered lasers to repair metal surfaces. The first step is to form the appropriate master alloy powder for the substrate that is being repaired and apply it to the surface of the substrate as a paint or thin film. The laser is then used to melt the master alloy layer into the substrate. The laser allows for uniform heating, precise control of location, and the laser dwells for short time periods allowing rapid cooling. The advantages of this process is the ability to select precisely the area to be modified, only small amounts of modifier alloy required, and the process is environmentally friendly and permanent.

E. Epoxy-Metal Composite (DEVCON)

High-performance, metal-filled epoxies permanently repair or rebuild critical equipment and quickly return it to service, minimizing expensive downtime and reducing costs. Metal-filled epoxies offer excellent resistance to a broad range of chemicals, good temperature resistance, and a room temperature cure. Plant personnel without special training can effectively apply it.

F. Electro-Spark Alloying (ESA)

The ESA process produces an electric arc through a moving electrode energized by a series of capacitors as it is short-circuited momentarily with the substrate. During the generation of the arc, small particles of the electrode material are melted, accelerated through the arc, impacted against the substrate, solidified rapidly, and built-up incrementally. The advantages to this process are the true metallurgical bond with substrate, substrate remains at/near room temperature, can form a wide range of surface alloys, unique geometry electrodes can be formed to process hard to reach crevices, and the surface buildup can occur with low to no heat affected zone.

IV. TESTING

A. High-Pressure Water Blast (HPWB)

Four 3" x 3" coupons with 20 mil defect repairs for each coating material by each technique were used to evaluate the adhesion and erosion of the repair material through use of the HPWB system. Two coupons were high-pressure water blasted without masking using the grease removal parameters. Two coupons were high-pressure water blasted using the paint removal parameters.

B. Salt Spray (Fog)

Three 3" x 3" coupons with 20-mil defect repairs for each coating material by each technique were used to evaluate corrosion of the repair and the perimeter of the repaired area. One coupon was exposed to a 5% salt spray environment per ASTM B 117 for 96 hours. The coating and substrate of each coupon were examined for corrosion. One coupon was exposed to simulated ocean water per ASTM D 1141 (without heavy metals) for 96 hours. The coating and substrate for each coupon were evaluated for corrosion each day according to the scale in ASTM D 610. One coupon was supposed to be exposed to inhibited soft water from the Component Refurbishment Center for two weeks with the exception of the coupons repaired by ESA due to the limited number of repaired coupons. This particular corrosion test was not done due to limits on repaired materials and time constraints.

C. Adhesion

Two coupons with 20-mil defect repairs for each coating material by each technique and all coupons from other test sections, which can be used once the other testing is complete, were tested with the P.A.T.T.I. tester according to LTP-2435-0988. The tensile strengths and failure modes were recorded.

D. Surface Roughness

Two coupons with 20-mil defect repairs for each coating by each technique were used to evaluate surface roughness. Surface roughness, rms, were determined by use of a Surtronic 10 stylus profilometer, or Hummel T500 stylus profilometer.

E. Thermal Cycling

Two coupons with 20-mil defect repairs for each coating by each technique were tested to determine the effects of thermal cycling on coating adhesion. The coupons were tape tested in accordance with MIL-STD-865C, heated to approximately 250°F, allowed to cool to room temperature and tape tested again. The coupons were then heated to approximately 350°F, and allowed to cool to room temperature and tape tested. The coupons were then heated to approximately 350°F, and cooled to room temperature an additional 19 times, then inspected for cracking or any other thermal expansion mismatch that could cause coating failure. The samples were tape tested a final time.

F. Hardness Test

For D-6AC steel substrate, two coupons with 20-mil defect repairs for each coating by each technique and one control (unblended, unrepaired) D6-AC coupon were evaluated using a Rockwell C hardness test with a Brale indentor and a 150 kg major load, for high strength steel. For 7075 aluminum specimens, two coupons with 10-mil defect repairs for each coating by each technique and one control (unblended, unrepaired) aluminum coupon were evaluated using a Rockwell B hardness test with a 1/16 in. ball under a 100 kg. major load. The repaired area and surrounding substrate were evaluated for hardness using the appropriate techniques.

G. Microhardness Test

This test was a deviation from the original planning and the reason for the need for this test is explained in this section. Some of the techniques required heat being applied to the substrate to repair the defect. This increase in temperature of the substrate and repair material led to a heat-affected zone (HAZ) for some of the materials. A HAZ is considered unacceptable because it can change the inherent properties of the substrate. In order to evaluate the effect of the HAZ on appropriate materials repaired by techniques using an increase in temperature, a microhardness test was done on the coupons to determine the size and effect on the substrate by the HAZ. Microhardness is similar to hardness testing with the exception that the sample is cross-sectioned and the microhardness is measured through the repair all the way down to the substrate. The sample is magnified and photographed which enables a view of the HAZ.

V RESULTS

The results of the testing done on the six repair methods will be presented in tabular form with results explained as pass/fail for each test done on the repaired coupons. The results are shown in Tables 1-6. The repair method that appears to be viable as a repair method for RSRM hardware is ESA. Surface Treatment Technologies, a private company based out of Maryland, accomplished the repair method ESA for this testing. The company can make the method for repair of specific parts, for example a curved cathode to fit into joints. The coupons were repaired with two different materials, D6-ac steel and Inconel 625. The coupons were machined after being repaired but were not polished; therefore, the surface roughness data is higher than for previously reported repair methods. The other tests performed on the repaired coupons were; P.A.T.T.I., high-pressure water blast, thermal cycling, salt fog, ocean water, hardness, and microhardness. As previously stated, the ESA repaired coupons successfully passed all the tests. More in-depth testing is planned, specifically on the HAZ concern.

VI CONCLUSIONS

Of all the processes studied ESA seems the most viable as an alternate for the repair of RSRM hardware. Even though this method seems to work that does not mean other methods cannot be looked at in order to keep from putting all the effort in one method that might not pass more extensive testing. The search for an alternate method should be an ongoing search since technology is constantly changing and improving. One method found late in this project that could be feasible if it is decided to explore it is Low Temperature Arc Vapor Deposition.

Table 1: High-Pressure Water Blast Test Results

Method	Material	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	Devcon material eroded from the D6-AC substrate with each pass of the HPWB nozzle.
Trowel Application	Devcon Epoxy-Composite Steel base	Devcon material eroded from the D6-AC substrate with each pass of the HPWB nozzle.
Wire Arc spray	95% Nickel	Material was not removed but had a grit-blasted appearance. Pores or voids become visible on surface.
Wire Arc spray	80/20 Nickel - Chrome	Material was not removed but had a grit-blasted appearance. Pores or voids become visible on surface.
Wire Arc spray	High carbon steel	Material was not removed but had a grit-blasted appearance. Pores or voids become visible on surface.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	No failures in HPWB using adhesive removal parameters (most aggressive), includes coupons which have cycled through other tests.
(MPTA)	Microblaze LM	Not used in lieu of other material
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	No failures in HPWB using adhesive removal parameters (most aggressive), includes coupons which have cycled through other tests. Small problem seen in one coupon along an incomplete weld bead.
(MPTA)	Inconel 718	Some small defects created from the HPWB, generally very small edge failures at substrate-repair transition.
(MPTA)	Stainless Steel 316	No failures in HPWB using adhesive removal parameters (most aggressive), includes coupons which have cycled through other tests.
Laser Induced Surface Improvement (LISI)	Fe/ Ni	Small anomalies seen from HPWB due to the initial material application, Surface Treatment Technologies engineer assures that any application can be improved significantly.
Electro-Spark Alloying (ESA)	D6-AC Steel	No failures in HPWB using adhesive removal parameters (most aggressive), includes coupons which have cycled through other tests.
Electro-Spark Alloying (ESA)	Inconel 625	No failures in HPWB using adhesive removal parameters (most aggressive), includes coupons which have cycled through other tests.

Table 2: Corrosion Test Results

Method	Material	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	No effects of corrosion from either 5% salt fog or simulated seawater in the composite material, the D6-AC steel has oxidized normally in the area surrounding the repair area
Trowel Application	Devcon Epoxy-Composite Steel base	No effects of corrosion from either 5% salt fog or simulated seawater in the composite material, the D6-AC steel has oxidized normally in the area surrounding the repair area
Wire Arc spray	95% Nickel	Heavy oxidation across entire surface of coupon. Signs of corrosion under repair area and a bubbling on repair area.
Wire Arc spray	80/20 Nickel - Chrome	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Wire Arc spray	High carbon steel	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	Repair has shown no effects of corrosion with either 5%salt fog or simulated seawater. The D6-AC substrate was heavily oxidized in salt fog and has begun to flake away.
(MPTA)	Microblaze LM	No test; material not used in lieu of other material which may perform better
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	Repair area has shown no effects of corrosion in either 5%salt fog or simulated seawater; surrounding D6-AC surface shows normal oxidation.
(MPTA)	Inconel 718	Repair area has shown no effects of corrosion in either 5% salt fog or simulated sea ater: un-repaired D6-AC shows normal oxidation.
(MPTA)	Stainless Steel 316	Repair area has shown no effects of corrosion in either 5% salt fog or simulated seawater: un-repaired D6-AC shows normal oxidation.
Laser Induced Surface Improvement (LISI)	Fe/ Ni	Simulated seawater had very minimal corrosion in both repair area and substrate. 5% salt fog had homogenous corrosion across entire surface of coupon , no failure of repaired area due to oxidized surface.
Electro-Spark Alloying (ESA)	D6-AC Steel	Repair area has shown normal oxidation for D6-AC in both 5% salt fog and simulated seawater: un-repaired D6-AC shows normal oxidation.
Electro-Spark Alloying (ESA)	Inconel 625	Repair area has shown no effects of corrosion in either 5% salt fog or simulated seawater: un-repaired D6-AC shows normal oxidation.

Table 3: Adhesion Test Results

Method	Material	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	Pull test adhesive had a partial failure.
Trowel Application	Devcon Epoxy-Composite Steel base	Pull test adhesive had a partial failure
Wire Arc spray	95% Nickel	Adhesive failure between the adhesive and the substrate and the repaired area remained unaffected
Wire Arc spray	80/20 Nickel - Chrome	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Wire Arc spray	High carbon steel	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	No pull was obtained.
(MPTA)	Microblaze LM	Not used in lieu of other material
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected
(MPTA)	Inconel 718	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected
(MPTA)	Stainless Steel 316	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected
Laser Induced Surface Improvement (LISI)	Fe/ Ni	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected
Electro-Spark Alloying (ESA)	D6-AC Steel	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected
Electro-Spark Alloying (ESA)	Inconel 625	Adhesive failure between the adhesive and the substrate while the repaired area remained unaffected

Table 4: Hardness Test Results

Method	MATERIAL	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	Test results were inconclusive due to partial hardness reading of the material substrate
Trowel Application	Devcon Epoxy-Composite Steel base	Test results were inconclusive due to partial hardness reading of the material substrate
Wire Arc spray	95% Nickel	Hardness values were obtained to an average of RHb of 65.9
Wire Arc spray	80/20 Nickel - Chrome	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Wire Arc spray	High carbon steel	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	Hardness values were obtained to an average of RHb of 66.1
(MPTA)	Microblaze LM	Not used in lieu of other material
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	Hardness values were obtained to an average of RHc of 24.4
(MPTA)	Inconel 718	Hardness values were obtained to an average of RHc of 20.2
(MPTA)	Stainless Steel 316	Hardness values were obtained to an average of RHc of 28
Laser Induced Surface Improvement (LISI)	Fe/ Ni	Hardness values were obtained to an average of RHc of 29.4
Electro-Spark Alloying (ESA)	D6-AC Steel	Hardness values were obtained to an average of RHc of 41.9
Electro-Spark Alloying (ESA)	Inconel 625	Hardness values were obtained to an average of RHc of 39.4

Table 5: Thermal Cycling

Method	Material	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	No anomalies were noted. Repair area appeared normal following thermal cycling.
Trowel Application	Devcon Epoxy-Composite Steel base	No anomalies were noted. Repair area appeared normal following thermal cycling.
Wire Arc spray	95% Nickel	No anomalies were noted. Repair area appeared normal following thermal cycling.
Wire Arc spray	80/20 Nickel - Chrome	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Wire Arc spray	High carbon steel	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	No anomalies were noted. Repair area appeared normal following thermal cycling.
(MPTA)	Microblaze LM	Not used in lieu of other material
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	No anomalies were noted. Repair area appeared normal following thermal cycling.
(MPTA)	Inconel 718	No anomalies were noted. Repair area appeared normal following thermal cycling.
(MPTA)	Stainless Steel 316	No anomalies were noted. Repair area appeared normal following thermal cycling.
Laser Induced Surface Improvement (LISI)	Fe/ Ni	No anomalies were noted. Repair area appeared normal following thermal cycling.
Electro-Spark Alloying (ESA)	D6-AC Steel	No anomalies were noted. Repair area appeared normal following thermal cycling.
Electro-Spark Alloying (ESA)	Inconel 625	No anomalies were noted. Repair area appeared normal following thermal cycling.

Table 6: Surface Roughness

Method	Material	Results
Trowel Application	Devcon Epoxy-Composite Titanium base	Average readings from the Taylor-Hobson Surtronic Profilometer were 48.3µin
Trowel Application	Devcon Epoxy-Composite Steel base	Average readings from the Taylor-Hobson Surtronic Profilometer were 64µin
Wire Arc spray	95% Nickel	Average readings from the Taylor-Hobson Surtronic Profilometer were 25.3µin
Wire Arc spray	80/20 Nickel - Chrome	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Wire Arc spray	High carbon steel	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Microblaze LM	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 718	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
High Velocity Oxygen fuel thermal spray	Inconel 903	No test; repair material did not maintain the necessary integrity during initial polishing to be considered for testing.
Microplasma Transfer Arc Weld (MPTA)	Inconel 625	Average readings from the Taylor-Hobson Surtronic Profilometer were 26.3µin
(MPTA)	Microblaze LM	Not used in lieu of other material
(MPTA)	Miles steel 1020	Not used in lieu of Stainless steel 316
(MPTA)	Ni 61	Average readings from the Taylor-Hobson Surtronic Profilometer were 7.3µin
(MPTA)	Inconel 718	Average readings from the Taylor-Hobson Surtronic Profilometer were 12µin
(MPTA)	Stainless Steel 316	Average readings from the Taylor-Hobson Surtronic Profilometer were 24.6µin
Laser Induced Surface Improvement (LISI)	Fe/ Ni	Average readings from the Taylor-Hobson Surtronic Profilometer were 5.3µin
Electro-Spark Alloying (ESA)	D6-AC Steel	Average readings from the Taylor-Hobson Surtronic Profilometer were 89.77µin
Electro-Spark Alloying (ESA)	Inconel 625	Average readings from the Taylor-Hobson Surtronic Profilometer were 77.72µin

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